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GAMMA-RAY SPECTROMETER STUDY

Robert M. Haralick, et al

Kansas University/Center for Research, Incorporated

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GAMMA-RAY SPECTROMETER STUDY

February, 1975

Final Report

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Prepared for

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Fort Belvoir, Virginia 22060

THE UNIVERSITY OF KANSAS CENTER FOR RESEARCH, INC.
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Gamma-ray spectrometer measurements have been applied to a large variety of problems in rock and soil mapping, terrain analysis, trafficability, snow water equivalent estimation, detection of environmental contamination by nuclear fission products, and direct and indirect mineral exploration. Fuller utilization of gamma spectrometric outputs is currently limited by the inadequacy of data reduction and presentation techniques. This report describes a data reduction technique designed to detect spatially contiguous ground regions which are homogeneous in thorium, uranium, and potassium content. The data

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reduction technique was applied to gamma-ray spectrometric data obtained at an altitude of 50 feet in the Garden City, Kansas area. Results indicate that 83% of the homogeneous areas detected by the technique can be directly interpreted on the basis of information contained in simultaneously obtained imagery.

THE UNIVERSITY OF KANSAS SPACE TECHNOLOGY CENTER
Raymond Nichols Hall
2291 Irving Hill Drive—Campus West   Lawrence, Kansas 66045

Telephone:

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PREFACE

This final technical report, which covers the period June, 1972 through 1 April 1975 was prepared jointly by the Remote Sensing Laboratory, Center for Research, Inc., The University of Kansas and Rice University, under Army Research Office-Durham grant 1321/E133/72. The work was administered under the direction of the Geographic Sciences Division of the U. S. Army Engineer Topographic Laboratories under Contract DAAK02-72-C-0550. Mr. Bob Brooke of that laboratory provided quidance as well as technical monitorship for this work.

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GAMMA-RAY SPECTROMETER STUDY

1. INTRODUCTION

The low natural gamma-ray flux from the land surfaces of the earth varies several orders of magnitude, depending upon the amounts of potassium, thorium, and uranium present in the surficial materials. Extensive theoretical and experimental research, including computer simulation and actual calibration of aerial surveying situations, have reduced to experimental practice the quantitative determination of thorium, uranium, and potassium (as well as a number of artificial fission products) from aerial data. The concentration data derived from gamma-spectrometric measurements have been applied to a large variety of problems: rock and soil mapping, terrain analysis, trafficability, snow water equivalent estimation, detection of environmental contamination by nuclear fission products, and direct and indirect mineral exploration. Fuller utilization of gamma-spectrometric outputs is currently limited by the inadequacy of data reduction and presentation techniques. For example, conventional radiometric contouring can lead to gross overestimates of the area of a high positive anomaly (Schwarzer, Cook and Adams; 1972). Another problem arises in situations where 10^4 spectra per day are obtained over terrain where there are marked fluctuations in the gamma-ray flux every few hundred meters or less. Some success in data reduction and presentation has been achieved by the application of statistical cluster analysis techniques (Schwarzer and Adams; 1973).

The present research was undertaken to develop a way to use gamma-ray spectrometer data to detect spatially contiguous ground regions which are homogeneous in thorium, uranium, and potassium content. We call such regions geochemical cells. In the surveys to date geochemical cells have been found to correlate closely to those geologic and soil categories that are fundamentally determined by mineral composition in general and potassium, uranium, and thorium concentration in particular.

II. GEOCHEMICAL CELLS: AN EXAMPLE

A geochemical cell is defined for this study as a volume of rock and soil that is homogeneous in thorium, uranium, and potassium contents to within experimental error. A relatively simple example is the flood plain of a meandering river, where the oxbow lakes represent a major geochemical cell shape and size. An oxbow lake filled with water to a depth of more than three feet has a very uniform and very low gamma-ray flux into the atmosphere. The low radioactivity of the water can be used as an operational local background and the fluctuations in these low counting rates can be used as a maximum measure of experimental variance in measuring a low homogenous flux from a geochemical cell. As an oxbow lake silts up and successively becomes a marsh and then dry land, the gamma-ray flux will increase markedly, but the size and shape of the geochemical cell would not necessarily change at all. The only exception would be the unlikely case in which the thorium, uranium, and potassium contents of the sediment, including organic material, filling the lake were precisely equal to those of the surrounding bank material.

In addition to the oxbow geochemical cells, the flood plain of a meandering river has cells corresponding to the crescent shaped meander "scars", which are composed of coarser, sand sized sediment left behind as the meanders migrated. To the extent that these crescent shaped scars are composed of feldspar and quartz sand grains they are generally found to contain less thorium and uranium than the other finer sediments in the flood plain; to the extent that these crescent shaped scars contain accessory sand sized minerals such as zircon and monazite they contain more thorium and uranium than the surrounding silts and clays. For a recent sedimentological description of meandering streams, their geometries, and their decade to decade changes, see Shelton and Noble (1974). In summary, the pattern of geochemical cells in the flood plain of a meandering stream is a jumbled overlay of segments of annuli and crudely nested crescents, which are rarely more than a few hundred meters across and more than a few kilometers along their longest curve. The thin and discontinuous veneer deposited by floods of the entire flood plain must exceed ten centimeters in thickness to radiometrically obscure the geochemical cells created by meandering.

II.1 Detection of Geochemical Cells

Much conventional aerial gamma-ray surveying is at too high an altitude and too fast a ground speed to resolve oxbow or meander scar geochemical cells. Quantitative formulations of the trade-offs with altitude, magnitude of flux changes or contrast, ground speed, detector volume, and time constant have been published elsewhere (Clark, Duval, and Adams; 1972). The gamma-ray spectrometer used in the present study consisted of a single 11 1/2 inch diameter by 4 inch thick NaI (Tl) detector, a digital ratemeter, an incremetal magnetic tape recorder in parallel with a six-channel strip chart recorder. Four discriminator channels were used: 1) an integral channel from 0.15 to 3.0 MeV; 2) a channel centered on the 1.46 MeV photopeak from the decay of potassium-40; 3) a channel centered on 1.76 MeV photopeak form the decay of dismuth-214 in the uranium-238 series; and 4) a channel centered on the 2.62 MeV photopeak from the decay of thallium 208 in the thorium-232 series. The narrow channels were set to have a bandwidth equal to 10 percent of the center photopeak energy.

The four channels of gamma-spectrometric data provide information about different aspects and volumes of the ground. For example: 1) the 2.62 Mev gamma photon from thallium-208 in the thorium-232 series can be detected from a greater average depth than the 1.46 MeV gamma photon from potassium-40; 2) crushed limestone on an unpaved road would add about 2.2 parts per million uranium right at the surface, but no thorium or potassium; 3) less moist ground would absorb less gamma-ray flux than moist ground, but the 1.46 MeV gamma photon from potassium-40 would be absorbed more than the 2.62 MeV from thallium-208.

Energy calibration was made with a cesium-137 source. The instrument used was designed, built, and calibrated at Rice University and is known as the Mark III. a summary description of this instrumentation and the routine methods of data reduction used in the present work are given by Fryer and Adams (1974). Operational experience, particularly with the surveying of flood plains near nuclear power reactor sites, has confirmed the theoretical formulations that an altitude of 50 feet, a ground speed of 50 m.p.h., a detector of NaI (Tl) that is 11 1/2" in diameter and 4" thick, and a time constant of 1 second, will detect each decrease in gamma-ray flux from a river or oxbow lake overflight. Additional operational experience with artificial geochemical cells with simple geometries such as flooded rice fields, fields heavily fertilized with phosphate fertilizer containing uranium, bauxite stockpiles, and water

filled pits and quarries confirm the conclusion that with the surveying parameters just given, there is more difficulty in recognizing and interpreting major geochemical cells than in their detection. The smallest geochemical cell that could be detected with the surveying techniques used could be a point source, providing that the gamma-ray flux and energy were high enough. More realistically, the instrument is predominately sampling an oval of ground about 100 meters along the flight line and 40 meters wide each second. A geochemical cell of these or larger dimensions could in principle be detected where the changes in fluxes from one cell to another were only a few percent of the total.

II.2 Recognition of Geochemical Cells

The boundaries of oxbow lake geochemical cells are readily recognized in conventional black and white aerial photography. Sandy and light colored meander scars are also recognizable with conventional black and white aerial photography. Many maps give only a generalized representation of the complex and ever changing river meandering and oxbow pattern. Many placer deposits that have been detected and recognized radiometrically are veneering with ordinary material so that there is only an occasional aerial photographic expression of the concentration of such black minerals as magnetite and ilmenite in placers.

Residual soils commonly reflect the thorium, uranium, and potassium contents of the underlying bedrock (Schwarzer, Cook, and Adams; 1972). Attempts to correlate radiometric geochemical cells with soil maps have achieved only limited success using cluster analysis techniques (Schwarzer and Adams; 1973). Some subtleties of soil classification relate in a direct way to the thorium, uranium, and potassium contents e.g. sand versus clay. Other soil classification distinctions, however, do not relate to the concentrations of these elements. Still another difficulty (and an interpretive opportunity) arises from second order ($\pm$ 10 to 25%) changes in the gamma-ray flux as ground moisture varies from minimum to maximum.

In summary, geochemical cells have been detected by gamma-ray spectrometry and correlated with aerial photographs (e.g. oxbow and meander scar cells) and with bed rock geology (e.g., residual soils). In order to detect, recognize, and correlate less obvious and minor geochemical cells, statistical techniques, particularly cluster analyses have been used to delineate geochemical cells. The present work is directed toward using a boundary delineation technique to locate the interfaces between geochemical cells. At the present stage in the evolution of our data reduction and presentation techniques, it appears that there may be many terrains suitable for the application of

a combination of the boundary delineation procedures described here, followed by a cluster analysis grouping of similar geochemical cells.

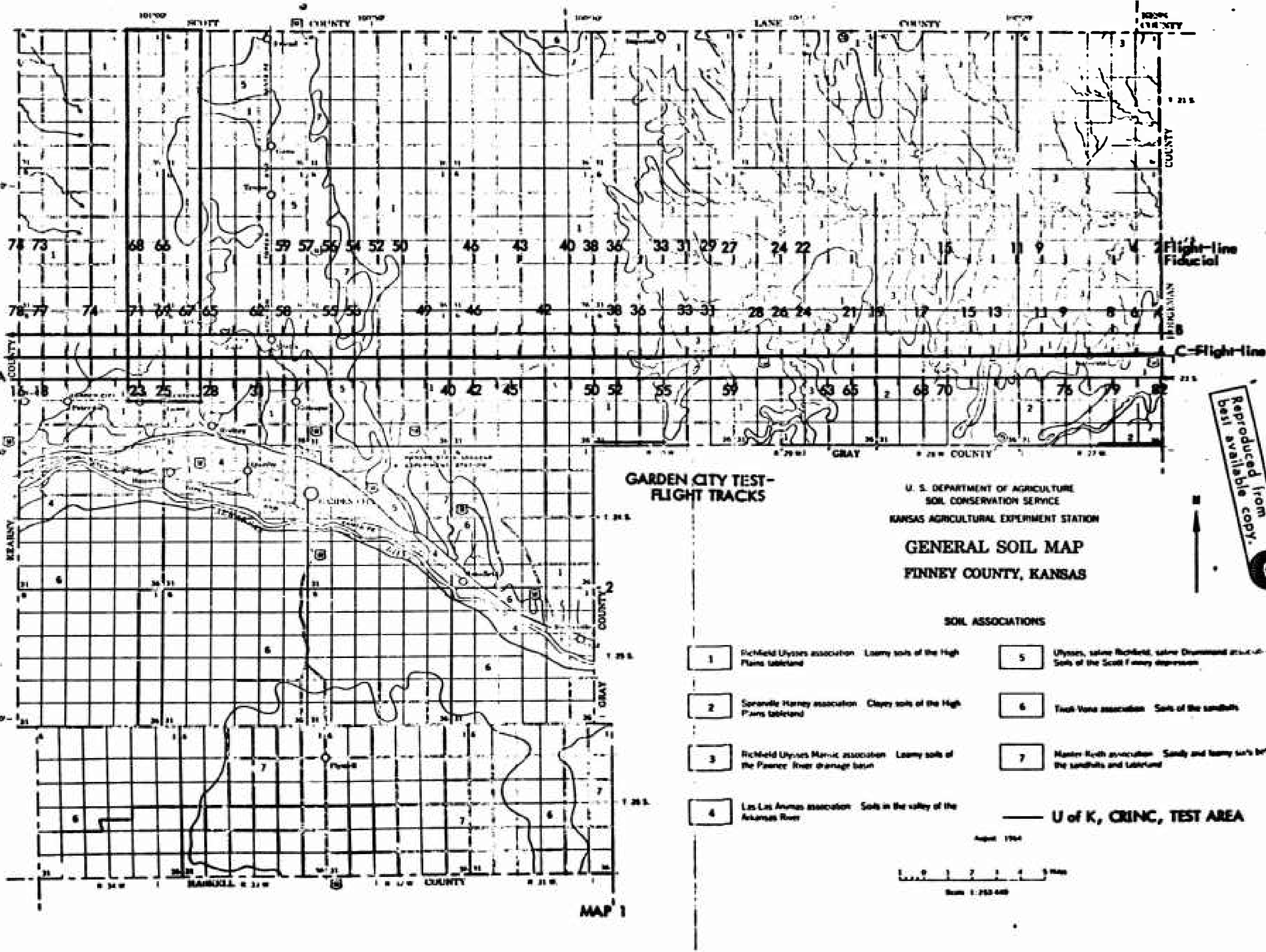
III. LOW ALTITUDE GAMMA-RAY SPECTROMETER SURVEY

The high cost and operational difficulties of remote sensing research require the flight planning give every consideration to many desireable, but sometimes conflicting objectives. The immediate objective of the joint Rice University-University of Kansas program was to apply, perhaps with special modification, the University of Kansas data analysis and image enhancing techniques to the aerial gamma-spectrometric data from the Rice Mark III. A longer range objective, necessitating simultaneous aerial surveys by both groups, was to correlate the gamma spectrometer data with other remote sensing data, particularly those affected by soil moisture. Of particular interest was the possibility that color Infra-Red or other techniques might correlate with ground moisture differences detected by the Rice gamma-ray spectrometer. The Garden City Test Area had the advantages that: 1) it is essentially flat; 2) section lines are - almost without exception - marked by roads or fences, providing a very convenient grid on the ground; 3) the area has a variety of soil types that have been mapped in recent years; 4) a number of different crops are grown in the area with different agricultural practices such as irrigation and fertilization; 5) the University of Kansas has accumulated a variety of data and experience in the area; 6) the base-line gamma-spectrometric data would provide an estimate of the suitability of the area for future studies on measuring the water-equivalence of snow cover by its absorption of the gamma-ray flux; 7) local logistical support including the availability of jet fuel for the helicopter were quite adequate. The major disadvantages of the Garden City Test Area for the gamma-ray experiment were: 1) its remoteness, causing a high moving on cost; 2) the similar lithologies and hence, the similar thorium, uranium, and potassium contents of the three geologic formations present in northern Finney County. Thus, the Garden City Test Area is much closer to the worst case than the average in terms of gamma-spectrometric differences, providing the necessary severe test of the boundary delineation technique for minor geochemical alls.

On October 11, 1972, gamma-ray spectrometric data were gathered from the Garden City area at an altitude of 50 feet by Professor J. A. S. Adams and his team from Rice University. At this altitude, the effective area "seen" by the sensor is a circle approximately 40 meters in diameter. To be sure that at least one good data line would be taken, the data were taken from three parallel flight lines on highway 156, one mile north, and one mile south of the highway. Almost 8,000 data points

were recorded along 144 line miles of flight. The flight line was chosen in an area which contains a relatively large variety of soil types for western Kansas. At the same time the Remote Sensing Laboratory took color IR, color Ektachrome, and red and green multiband imagery with a four camera Hasselblad cluster mounted on the CRES plane. The plane flew at 3,000 feet and obtained 70 mm frames over the flight line. Over 100 frames were obtained.

The gamma-ray data were recorded in real-time on a digital tape in the helicopter with "fiducial" markers manually inserted on the tape as the helicopter flew over road or fences marked section, half-section, or quarter-section lines. Each time that a fiducial was inserted, the corresponding point was marked on a map and the fiducial number noted. The correspondence between the marked map and the imagery then established over which small area ground patch each gamma-ray measurement was taken. Map 1 shows the flight-line flown. Gamma-spectrometric backgrounds were flown over Lake Buchanan before and after the overflights.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SCOTT COUNTY
LANE COUNTY
KEARNY COUNTY
GRAY COUNTY
HASKELL COUNTY
HODGEMAN
B-Flight-line Fiducial
C-Flight-line
GARDEN CITY TEST-FLIGHT TRACKS
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
KANSAS AGRICULTURAL EXPERIMENT STATION
GENERAL SOIL MAP
FINNEY COUNTY, KANSAS
SOIL ASSOCIATIONS
1 Richfield-Ulysses association Loamy soils of the High Plains tableland
2 Spearville-Harney association Clayey soils of the High Plains tableland
3 Richfield-Ulysses-Mansic association Loamy soils of the Pawnee River drainage basin
4 Las-Las Animas association Soils in the valley of the Arkansas River
5 Ulysses, saline Richfield, saline Drummond association Soils of the Scott-Finney depression
6 Tivoli-Vona association Soils of the sandhills
7 Manter-Keith association Sandy and loamy soils between the sandhills and tableland
U of K, CRINC, TEST AREA
August 1964
Scale 1:253 440
MAP 1

IV. MATHEMATIC DESCRIPTION OF PROCESSING TECHNIQUE

The speed, versatility, and low cost per calculation of modern electronic computer data processing provide many alternative design opportunities for defining homogeneous regions in sequential data - or, conversely - enhancing the boundary between homogeneous regions. In the present case, the objective is to define geochemical cells by testing their internal homogeneity to within experimental error as defined by conventional counting statistics.

During each one second sampling period, the gamma-ray spectrometer produces four numbers, one from each of the discriminator channels described earlier. We will think of these four numbers as a 4-dimensional vector. As the helicopter flies along its flight line, a sequence of 4-dimensional vectors is produced. Let $\langle X_1, X_2, \ldots, X_N \rangle$ be the sequence of N 4-dimensional vectors produced by the gamma-ray spectrometer in a period of N seconds. We seek a procedure to delineate the natural boundaries occurring in this sequence. We interpret the corresponding ground region inbetween the successive boundaries as a geochemical cell.

The gamma-ray spectrometer data indicate a boundary when there is a sufficiently large difference between the vector immediately previous to the boundary and the vector immediately following the boundary. Conversely, the gamma-ray spectrometer data indicate a homogeneous area when the successive differences of the data vectors are sufficiently small.

Since we are interested in differences, it is natural to form the sequence of successive differences:

$$\langle Y_1, \ldots Y_{N-1} \rangle \text{ where } Y_n = X_n - X_{n+1},\ n = 1, 2, \ldots N-1$$

Each Y vector is a 4-dimensional vector whose components are the differences of successive measurements from the same channels of the gamma-ray spectrometer. The general idea of processing is to determine when these differences are large enough to be significant. The problem is that differences are very sensitive to noise and correlation and a processing technique that takes the sum of the squared absolute differences, for example, can produce many false high values. We illustrate the reason for this situation graphically in Figure 1. There, the x and y axes represent two components of the difference vector Y and the figure depicts the situation where the components are significantly correlated. The elliptical

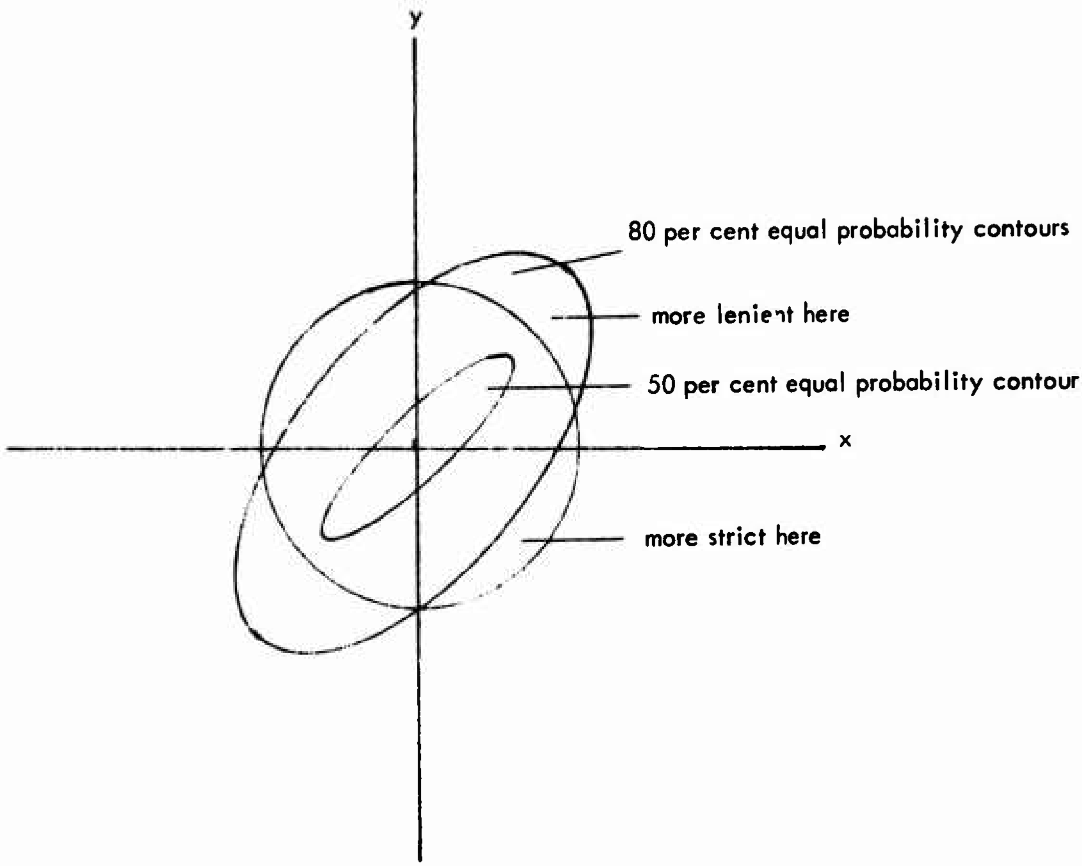

FIGURE 1. Illustrates the comparison between using simple length (the circle) and the natural elliptical contours for deciding when the difference vector (γ) is large enough. Note the areas where the circle is more strict than or more lenient than the elliptical equal probability contours which naturally take into account the correlation between components of the difference vector.

contours represents the 50 per cent and 80 per cent equal probability contours so that 80 per cent of the time, for example, the measurements will fall within the larger eliipse.

If we use an clgorithm which determines significant enough difference by the sum of the squared successive differences being great than a specified amount, we in effect say that all measurement falling outside the circle constitute significantly high differences. Notice that the circle does not follow the natural equal probability contour lines. The regions which are within the circle yet outside the 80 per cent contour line consititute an area where the threshold is too strick so that the procedure can miss boundaries. The region inside the 80 per center contour ellipse and outside the circle constitutes an area where the threshold is too lenient; therefore, such a procedure can indicate boundaries where none exist.

The solution to this problem is to say that the vector Y represents a significant difference whenever it lies outside of a specified equal probability ellipse. Assuming that the distribution of Y is ellipsoidally symmetic with mean zero, we can show that the quadratic form $Q = Y' \sum^{-1} Y$, where $\sum$ is the covariance matrix for Y, is the appropriate statistic.*

The quadratic form technique very nicely takes into account the correlation between components in the difference vector. It can, as easily, take in account the spatial correlation between successive difference vectors if we form a sequence of stacked successive difference vectos and use them instead of the Y vectors. Each such stacked successive difference vector Z contains components from the difference vectors in its own local spatial neighborhood. Formally, the successive difference sequence formed by stacking k successive difference vectors together is defined by

$$< Z_1, Z_2, \ldots, Z_{N-k} > \text{ where}$$

$$Z_n = \begin{pmatrix} Y_{n-\left[\frac{k}{2}\right]} \\ Y_{n-1} \\ Y_n \\ Y_{n+1} \\ Y_{n+\left[\frac{k}{2}\right]} \end{pmatrix} \text{ for k odd and } Z_n = \begin{pmatrix} Y_{n-\left(\frac{k}{2}\right)} \\ Y_{n-1} \\ Y_n \\ Y_{n+1} \\ Y_{n+\left[\frac{k}{2}\right]} \end{pmatrix} \text{ for k even.**}$$

Let $\sum$ be the covariance matrix of this Z sequence of vectors and be the mean of this Z sequence of vectors. We compute the magnitude of each vector relative to $\sum^{-1}$ thereby constructing the sequence Q. In effect this will give us a measure of differences which takes into accound component correlation and which is invariant to bias or linear scale changes.

$$Q = \langle q_1, \ldots, q_{N-k} \rangle \text{ where}$$

$$q_n = (Z_n - \mu)' \sum^{-1} (Z_n - \mu).$$

Because differencing operations tend to magnify noise it is desireable to smooth the sequence Q by taking a running average. Large enough departures from the smoothed sequence should then indicate where there are boundaries between one geochemical cell and the next.

Fine tuning of the selected probability or significance criteria for the processing must be based on experience and fine tuning should reduce but not eliminate the number of two opposing cases: (1) a real boundary is missed because the components of vector Z do not meet the criteria of significance; (2) a false boundary inside a geochemical cell is generated by either random error in instrumentation or by a rare statistical run that has maximum deviations of the same sign in all components of vector Z exceeding the

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* Where y' denotes y transpose.

** [w] is the largest integer smaller than or equal to w.
(w) is the largest integer smaller than w.

significance criteria. The initial processing results using a stacking of 3 and running average of 5 is illustrated and discussed in the next section. The results are encouraging because the processing and criteria of significance used generate boundary indications that correlate closely in most cases with ground differences visible in the aerial photography. We suspect that those indicated boundaries that do not correlate with anything visible in the photographs may still be real physically.

V. RESULTS

In contrast to the experience in the Puerto Rico and Oklahoma surveys (Schwarzer, Cook and Adams; 1972), (Schwarzer and Adams; 1973) the Garden City strip chart and computer generated profiles which is illustrated in Figure 2 appear monotonous and without character to the eye, regardless of which of the four spectral channels are examined. This is due to the relatively dry summer and fall weather and the soil characteristics in the area. A conventional and conservative statistical requirement for significance, e.g. a 2 sigma difference to define an anomaly, would lead to the conclusion that this Kansan plain is flat and uniform, both topographically and radiometrically. Thus it is interesting how the boundary delineation technique is able to portray differences simultaneously occurring in all the channels while the eye has a hard time seeing significant differences in any one channel alone.

We will discuss our results by illustrating for each mile an aerial photograph showing the flight line. Below the photograph and on the same scale we will plot the smoothed Q sequence. Small area ground patches having corresponding high q values are indicative of boundaries. Along with each illustration we will provide a running commentary suggesting an interpretation for each boundary and geochemical cell.

In Figure 3 (and subsequent figures) the flight line of the gamm-spectrometric survey is defined by the two arrows pointing into the aerial photograph. The edges of aerial photographic coverage in each print are marked by x's in the diagrams below the figures. In the diagrams below each photograph the smoothed Q sequence is graphed. It indicates boundaries from the data processing described in Section IV. Soil moisture estimates from the Infra-Red photography are indicated in the diagram (M = moist, W = wet, and D = dry). At the bottom of the diagram below each graph the soil type is indicated according to the abbreviations and classification given in Appendix A.

In Figure 2 the spike centered on Fudicial 41 is interpreted as being related to the unpaved section road itself or to the differences between the gamma-ray signatures in the two fields on either side of the road. By comparison the spike at the far left on the other side of the light field has nearly the same width and slightly greater height than the Fiducial 41 spike. The four narrow spikes and very large spike in Figure 3 are in a single field on the ground and do not correlate clearly with any contrast differences in the black and white photograph. However, the largest spike in Figure 3, together with the smaller spike to its right correlate with the boundaries of the Randall clay

(abbreviated Ra in Figure 3 and described in Appendix A). This proposed correlation of the largest spike in Figure 3 with the Randall clay is supported by the observation that the highest spike in Figure 4 also correlates with the Randall clay and that the small strip of Randall clay in Figure 6 also correlates with a small spike (due to photographic overlap this same spike is also reproduced in Figure 7). It should be further noted that there are no other crossings of the Randall clay; in other words, we have no case of the Randall clay not causing a spike at its boundary. Physically the relative amounts of thorium, uranium, and potassium in the Randall clay may give rise to the gamma-ray spectrometric signature that will provide enough contrast to nearly always enhance the boundary indicated by the data processing. Alternatively, an interpretation could be based on the observation that the Randall clay is usually associated with depressions where ponding and frequent drowning of crops occur (see Appendix A for details). The three apparently uncorrelated small spikes in Figure 3 may be due to very wet conditions in small depressions or they may be artifacts resulting from statistical runs that accumulated in the data processing so as to meet the criteria for a boundary. Only detailed ground checks could confirm the reality of these three small spikes.

In Figure 4 the highest spike matches the Ra to Rm soil type contact precisely, as noted above. The narrowest and lowest spike in Figure 4 coincides with a farm trail along a half section line. The twin peaked and wide spike near the center of Figure 4 correlates roughly with the M-W-M (moist-wet-moist) boundary. It should be noted that a steep enough gradient in moisture content could generate a broader and broader spike as the five point moving average moved along the gradient. The moist to wet Ulysses silt loam (Ub) on one side of Fiducial 43 has a closely correlated spike, but there is no spike associated with the dry to moist Ub on the other side of Fiducial 43. Fiducial 43 is a gravel section road that has a very broad double spike associated with it. This was precisely the association with the gravel road at Fiducial 41 in Figure 3 and can also be seen at Fiducial 44 (Figure 6), Fiducial 46 (Figure 7), Fiducial 47 (Figure 9), Fiducial 48 (Figure 10), Fiducial 50 (Figure 12), Fiducial 52 (Figure 13), and Fiducial 54 (Figure 15). These gravel road spikes are not all centered on the fiducials because the road may not be exactly in the center of the ground covered in the one second counting interval. The breadth and shape of the gravel road spikes vary depending on the contrast with the gamma-spectrometric signatures on either side of the road.

In Figure 5 Fiducial 43 and its associated spike from Figure 4 are reproduced again. The three spikes may be related to a combination of soil type boundaries and soil moisture changes. Thus, spikes on the Ka (Keith loam) are near moist to dry contacts. Spikes on Ub (Ulysses silt loam) are near where the loam is considered moist on the basis of the Infra Red photography interpretation. Fiducial 44, as mentioned above is a farm road and is associated with a spike.

In Figure 6 the sharp spike on the moist to wet Ra (Randall clay) was cited as one of the three out of three such cases in this survey (see discussion of Figure 3 above). As in Figure 5, moist Ub is associated with a spike. The smallest spike in Figure 6 is at a moist to wet boundary on the Uc, which is a sub-classification of the Ulysses silt lo loam. The spike from the Mr (Mantos fine sandy loam) correlates exactly with a quarter section fence trail.

In Figure 7 there is a broad four pronged spike correlating with four rapidly changing soil types on which there is a moisture gradient from wet to dry. Fiducial 46 is another gravel section road with a sharp spike next to and merging with a slightly higher spike at a dry-wet boundary that provides the maximum moisture contrast in the processed data. The spike on the Ra to the left in Figure 7 has already been discussed above. The small spike to the right of Fiducial 46 does not correlate with anything in the photo or other data.

In Figure 8 the small uncorrelated spike on Figure 7 is reproduced again. The very large and broad spike in Figure 8 correlates with the Ue (Ulysses-Colby silt loam). The other two crossing of this soil type (Figures 14 and 15) also have one edge of this geochemical cell marked by a very broad and high peak. The light areas along the survey flight line in Figure 8 are believed to represent areas where the darker topsoil has been eroded away, leaving the lighter more calcalerous Ue (see Appendix A). Some gamma-ray flux is penetrating the thinning veneer of Rm, causing a gradient that in turn generates a broad spike in the data processing. The small spike in the middle of the Ue corresponds nicely with the dark hockey stick shaped area on the photograph, which is considered to be a topograhic low, as Ue is usually light colored and found on the tops or crests of slopes. The gamma-spectrometric data as represented by most if not all the spikes in Figure 8 suggest that more Ue is within 20 centimeters of the surface than is mapped and that the light areas in the photograph are more representative of the situation on the ground than the simple Rm-Ue-Rm sequence mapped. The smaller twin peaked spike in Figure 8 correlates only with the light to dark patches in the photograph and may represent Rm veneering over Ue. The higher twin peaked spike straddles

a moist to wet boundary, but many such boundaries do not correspond with spikes. The small sharp spike at the edge of the photograph does not correlate with anything in the mapping or photography, except its proximity to a wet to moist boundary.

In Figure 9 the two twin peaked spikes and small spike from Figure 8 are reproduced. The very broad spike straddling the gravel road along Fiducial 47 also straddles a moist-wet-moist sequence and toward the center of the print moves into a circular area that was formerly irrigated (a more distinct example can be seen in Figure 10). Once again the broadness of the Fiducial 47 spike may be due to moving down some gradient from the road to the circular area. The twin peaked spike in the circular area does not correlate with any of the other parameters studied. One of the two small spikes in the circular area corresponds with a moist-wet boundary, but the other is uncorrelated.

In Figure 10 the flight line is almost precisely tangental to the well defined circular irrigation area and there is a twin peaked spike as the flight line becomes tangent. This twin peaked spike may be a physical artifact, if potassium and/or uranium containing phosphate fertilizers were also intensively used on the irrigated land. The small spike centered on the gravel road along Fiducial 48 is of particular interest because it is the smallest gravel road spike observed and is also the only case where the land is also dry for some distance on either side of the road. In all the other cases of gravel roads at Fiducials the composition difference provided by the road is enhanced by the moisture differences and gradients as the road was approached and left behind. The twin peaked and sharp spikes to the right of Fiducial 48 do not correlate with any of the other parameters measured.

In Figure 12 the spike peak at the gravel road along Fiducial 50 is readily correlated. The two narrowest and lowest spikes are at field boundaries. The broader peaks do not correlate with known parameters and we favor the hypothesis that they may be physical artifacts, perhaps from potassium or uranium containing phosphate fertilizers.

In Figure 13 the spike associated with the gravel road along Fiducial 52 is offset, almost certainly due to the random accident as to when the one second counting interval began as the road was approached. Alternatively, the offset may be related to the white lineation (road ditch?) paralleling the road on the side of the offset. The single spike to the left of Fiducial 52 correlates nicely with the farm

structures. To the right of these single spikes are two spikes that are precise mirror images of each other, this is the only such case observed and is most peculiar. The double and triple peaked spikes in Figure 13 do not correlate with any of the other observations.

In Figure 14 the highest spike in the multi-peaked spike at the center correlates with both a road and a Ua to Ub soil boundary. The second highest peak correlates with Ub to Um soil boundary. The broad peak at the right is assigned to a veneering of Us over Ue soil type (see discussion in Figure 8), with a single spike at the Um to Ue contact. The broad tri-peaked spike at the left does not correlate with any other observations.

In Figure 15 the spikes associated with the Ue soil type are reproduced. Once again a prominent peak is associated with the gravel road along Fiducial 54 with a slight offset due to the accident of when the one second counting period began as the road was approached. The spikes to the right of Fiducial 54 contain 6 peaks in a half mile of traverse that has 6 changes in soil types.

Clearly, the gamma-ray spectrometer is telling us something about what is going on in the upper few feet of the earth's surface. Soil type information is part of what the spectrometer can tell us from overall radiation levels. There might be other kinds of information such as frequency of cancer which could be related to overall radiation levels. The area is rich with possibilities needing exploration.

VI. RECOMMENDATIONS

Because the gamma-ray data are expensive to obtain and because only a small portion of the gamma-ray data archived at Rice University have been analyzed with the data reduction technique described herein, we recommend that an effort be undertaken to apply the data reduction technique and to interpret the resulting homogeneous regions and boundaries on this existing gamma-ray spectrometric data.

VII. CONCLUSIONS

We have described a gamma-ray spectrometric data reduction technique designed to detect spatially contiguous ground regions which are homogeneous in thorium, uranium, and potassium content. The data reduction technique is based on boundary determination from a correlated data sequence.

This very first attempt to understand the significance of the results of the data processing are most encouraging. Certain soil types such as the Randall clay (Ra) and Ulysses-Colby silt loam (Ue) appear to have resolvable and consistent geochemical cell boundaries. Unambiguous artifacts such as gravel roads are associated with spikes. A major variable is moisture and it is quite possible that the processed gamma spectrometric data are able to define more than three categories of moisture, with particular sensitivity to gradients. Furthermore, the processed gamma-spectrometric data may also be able to see finer soil changes, including veneering that is not conventionally mapped. The significance of the mirror image twin peaks in Figure 12 is a prime target for future investigation. At this very preliminary stage of investigation, we find no basis to reject any of the spikes as data processing artifacts. However, we have no interpretive hypothesis for some 10 of the 57 spikes.

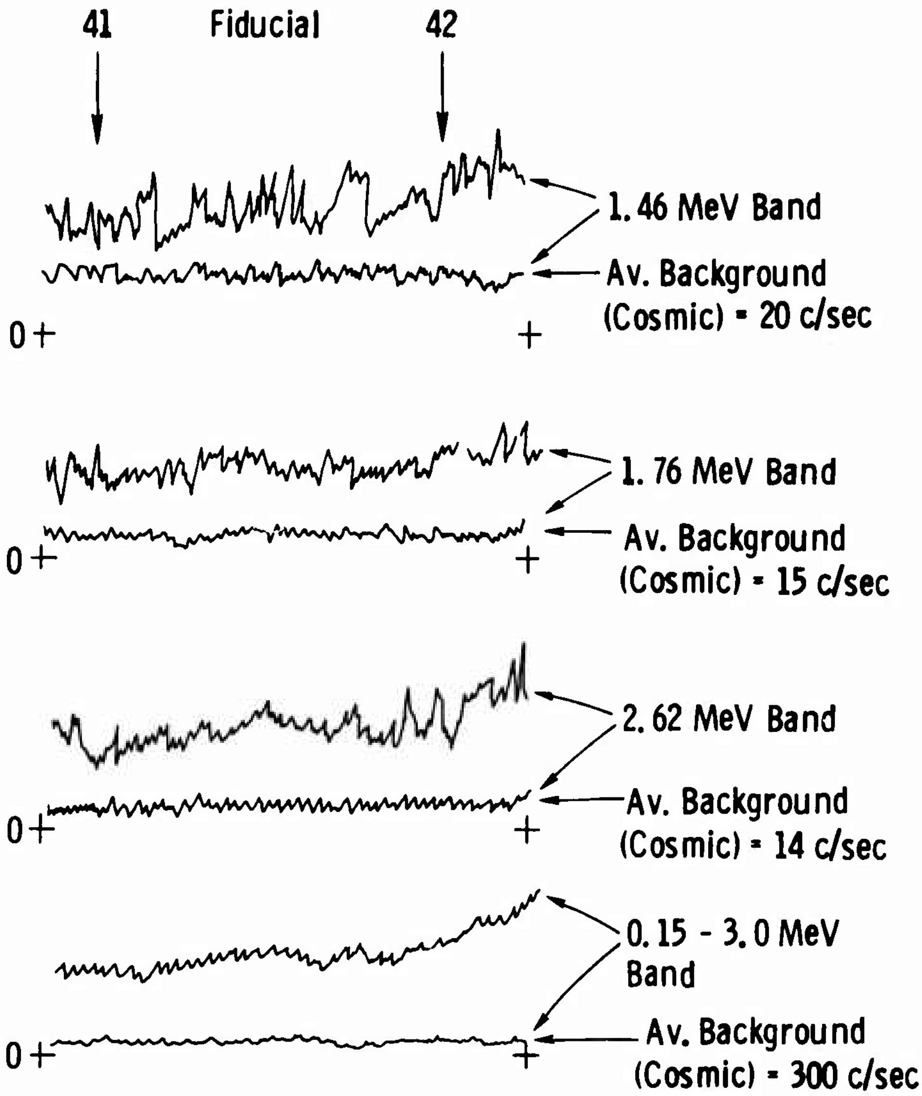

Figure 2. Illustrates a section of the strip chart produced by the gamma ray spectrometer between feducial 41 and 42.

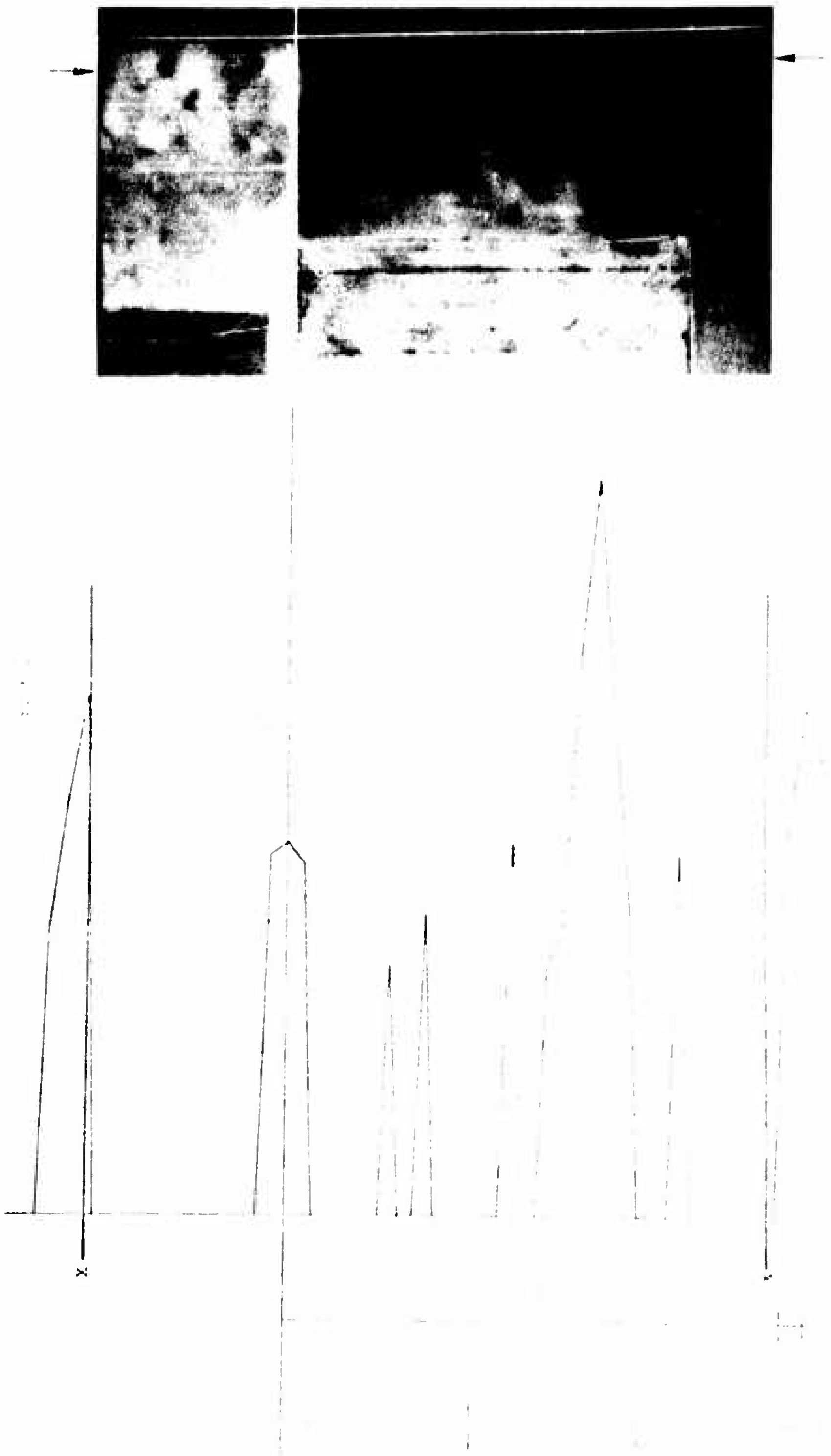

Figure 3. Fiducial 41

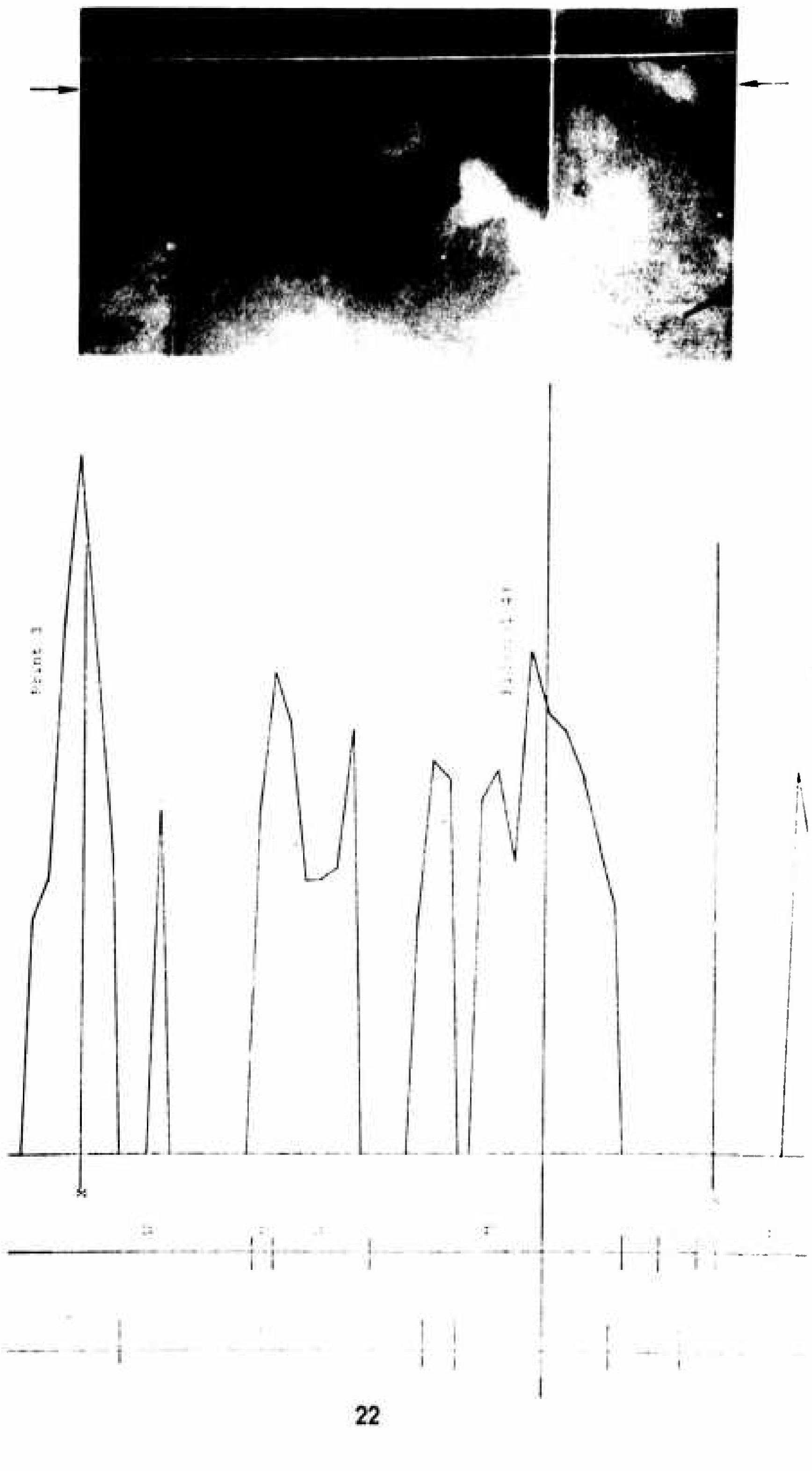

Figure 4. Fiducial 43

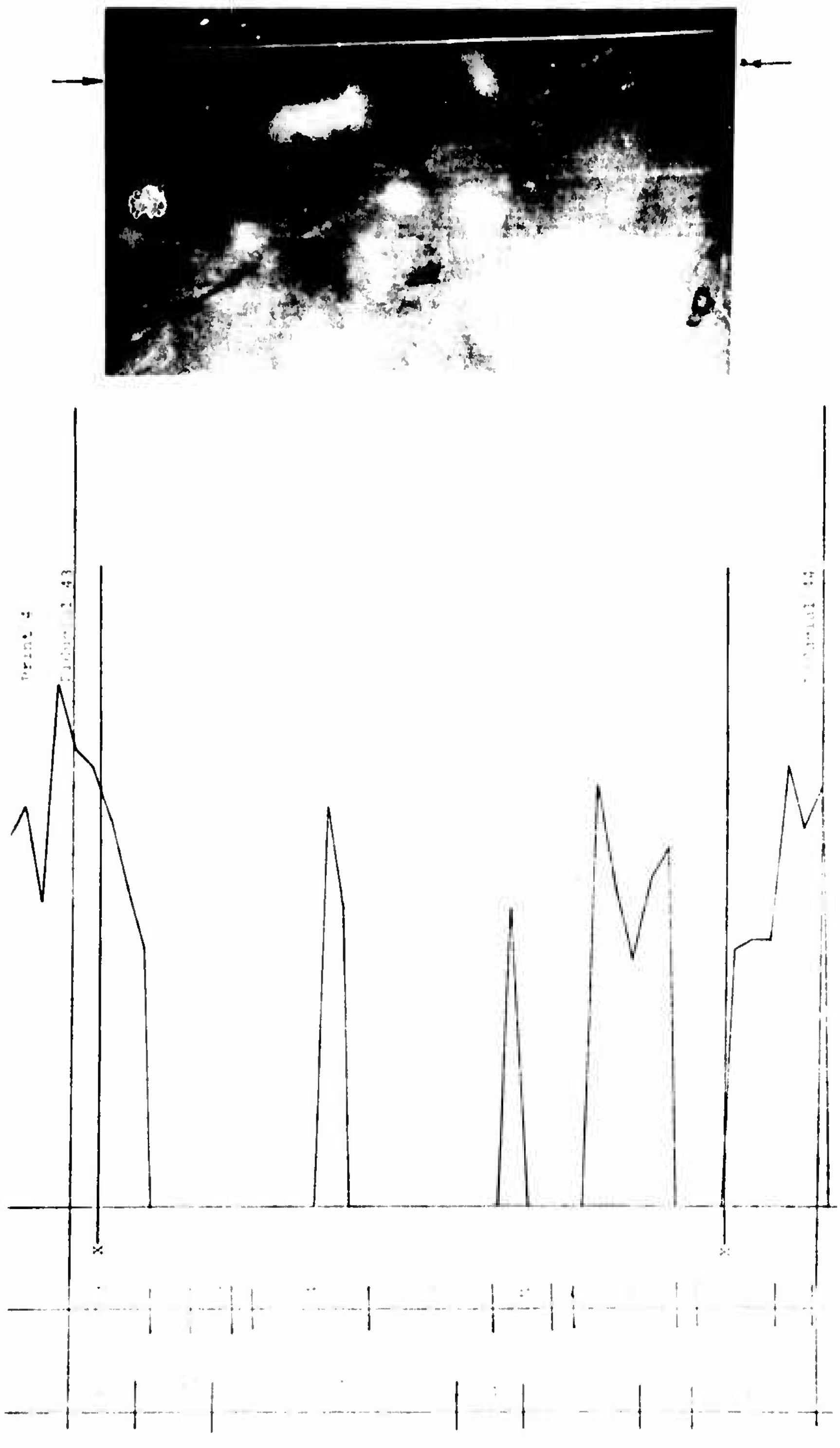

Figure 5. Fiducial 43-44

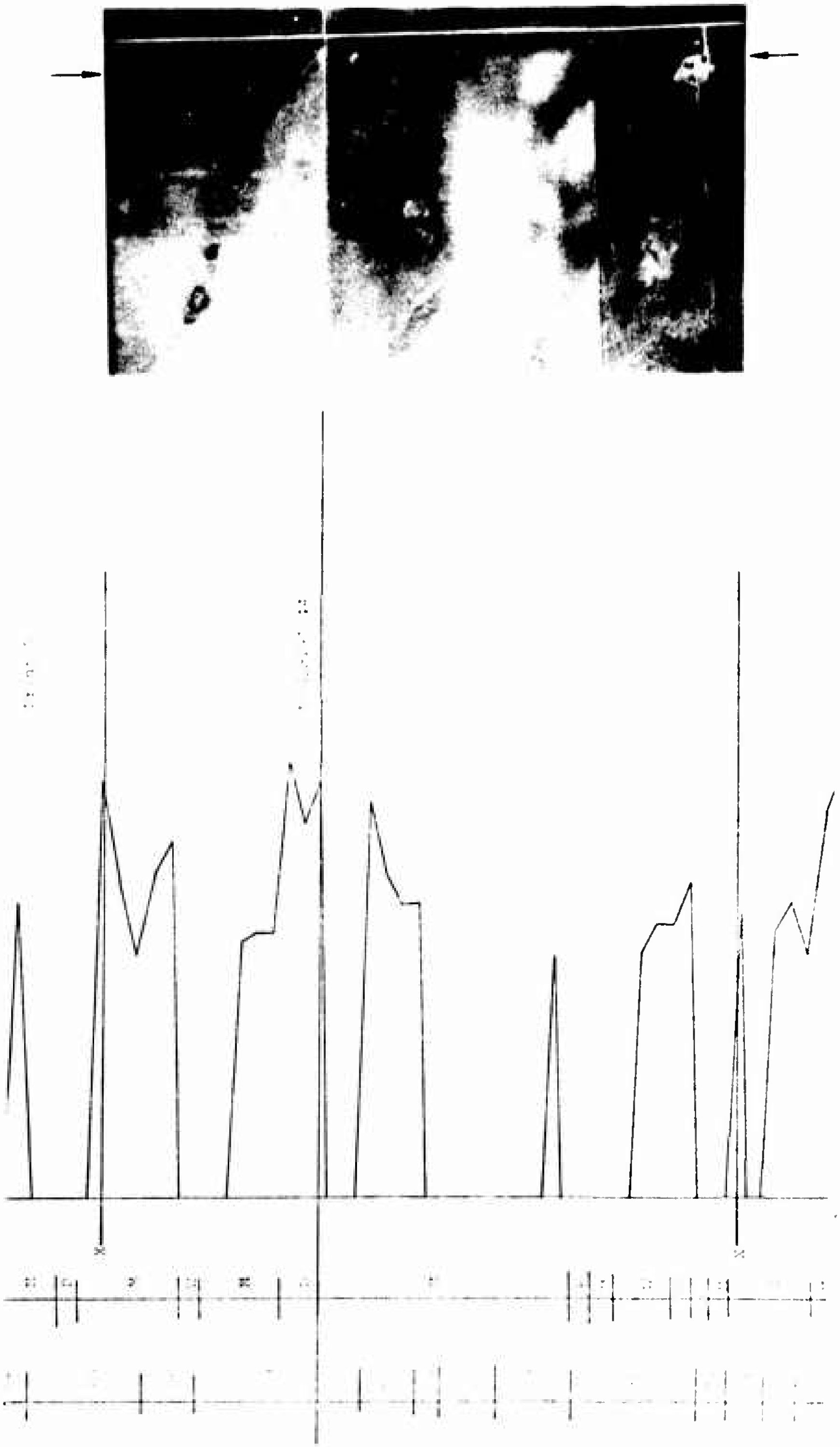

Figure 6. Fiducial 44

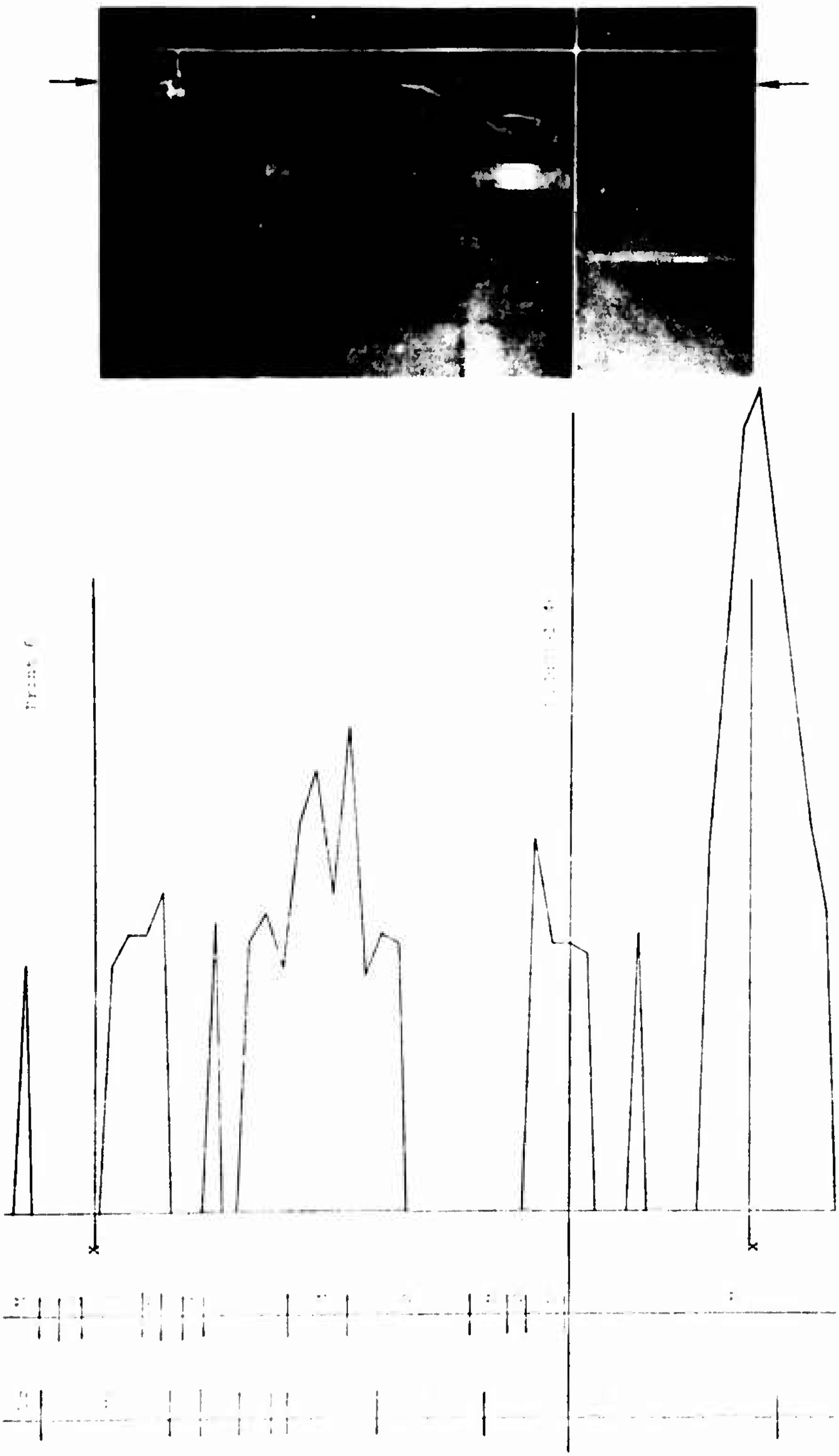

Figure 7. Fiducial 46

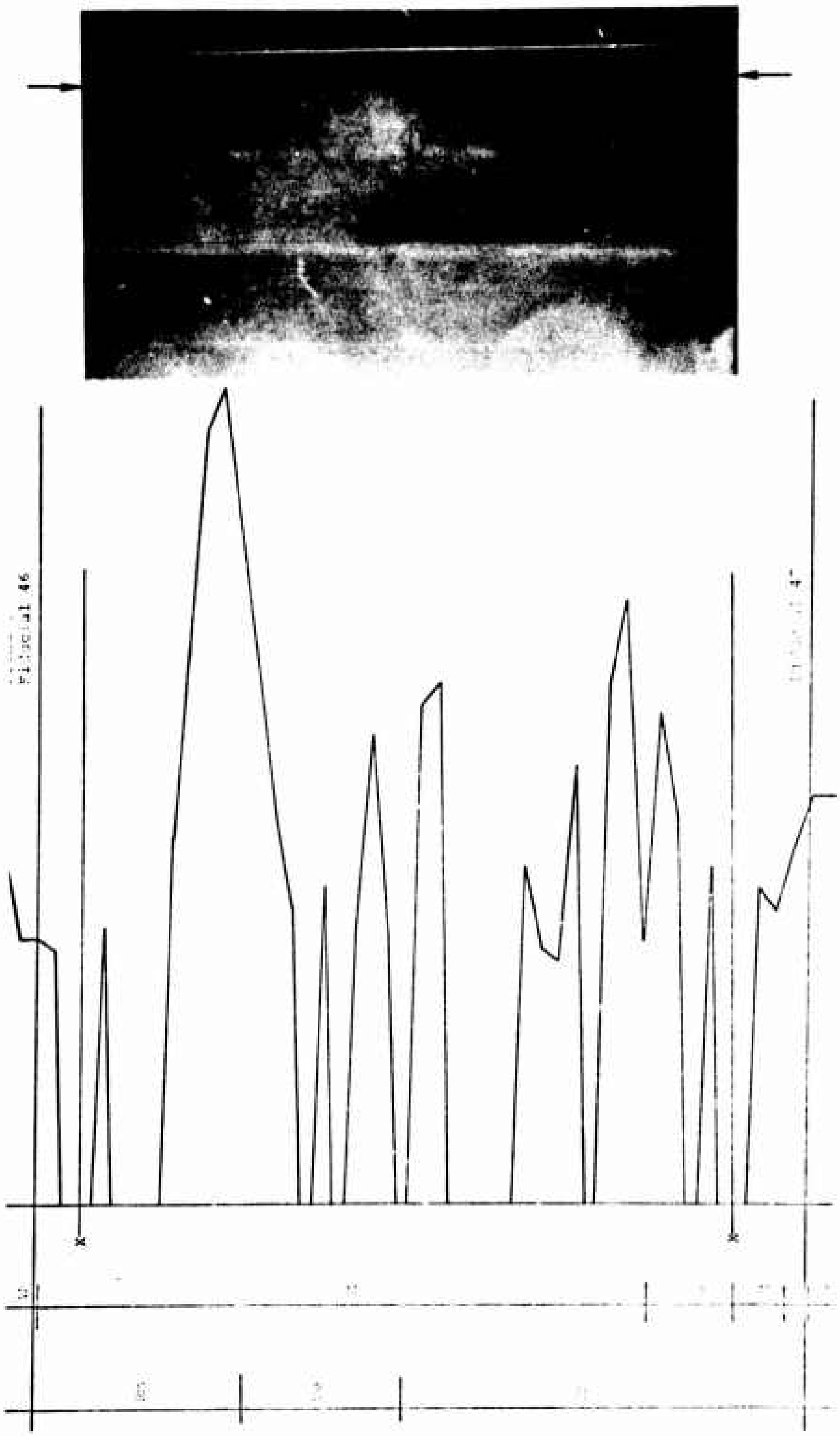

Figure 8. Fiducial 46-47

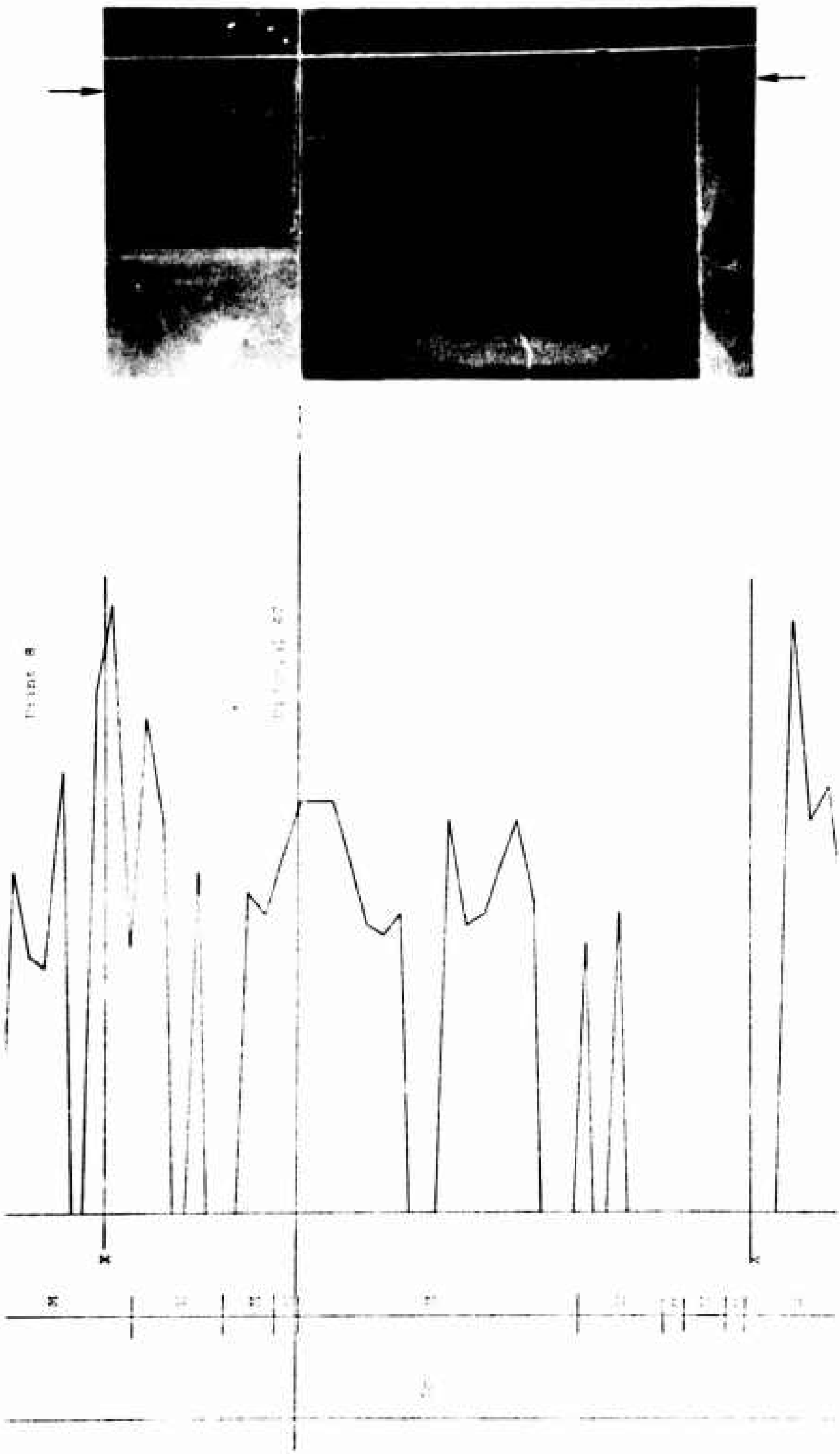

Figure 9. Fiducial 47

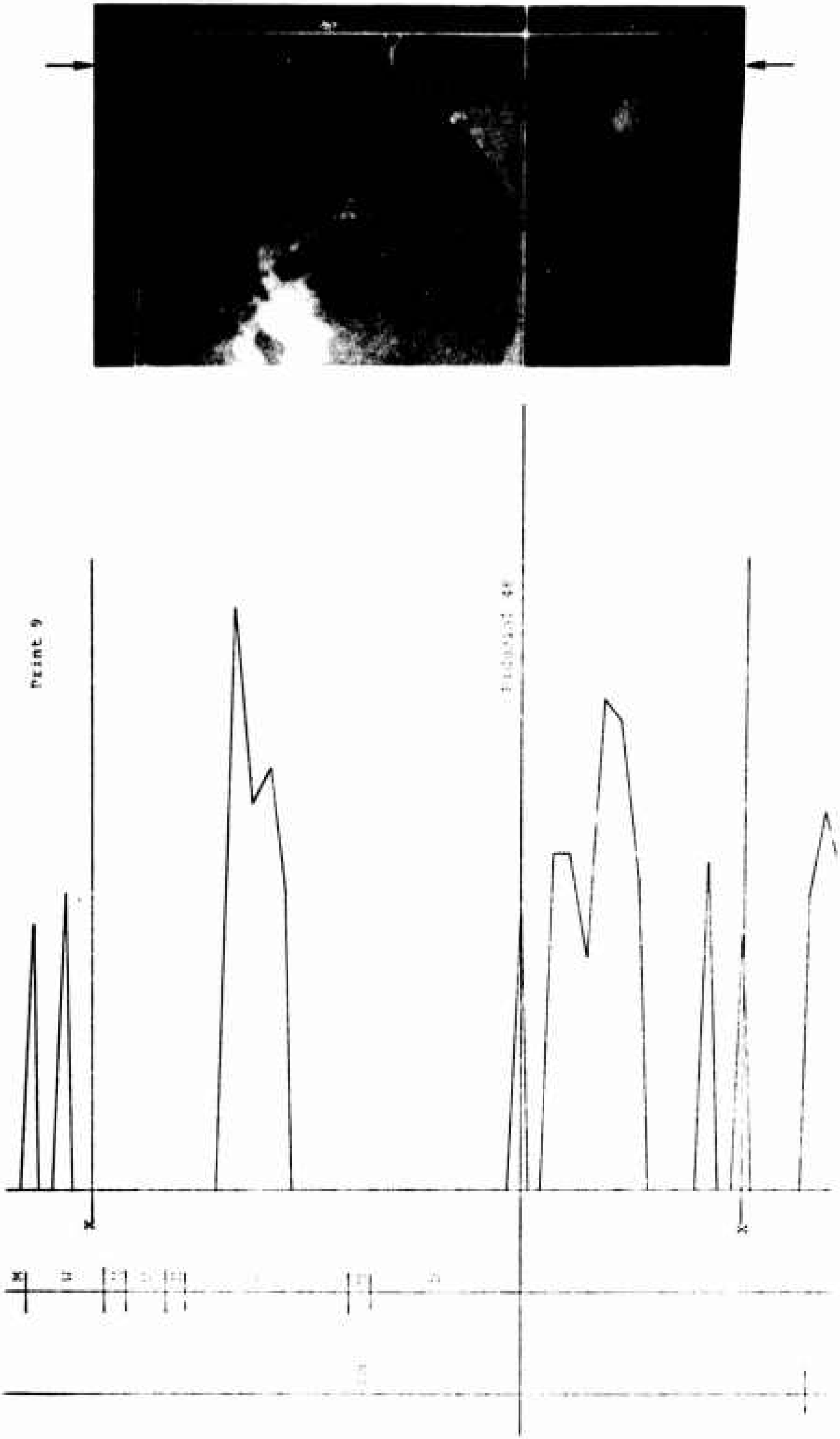

Figure 10. Fiducial 48

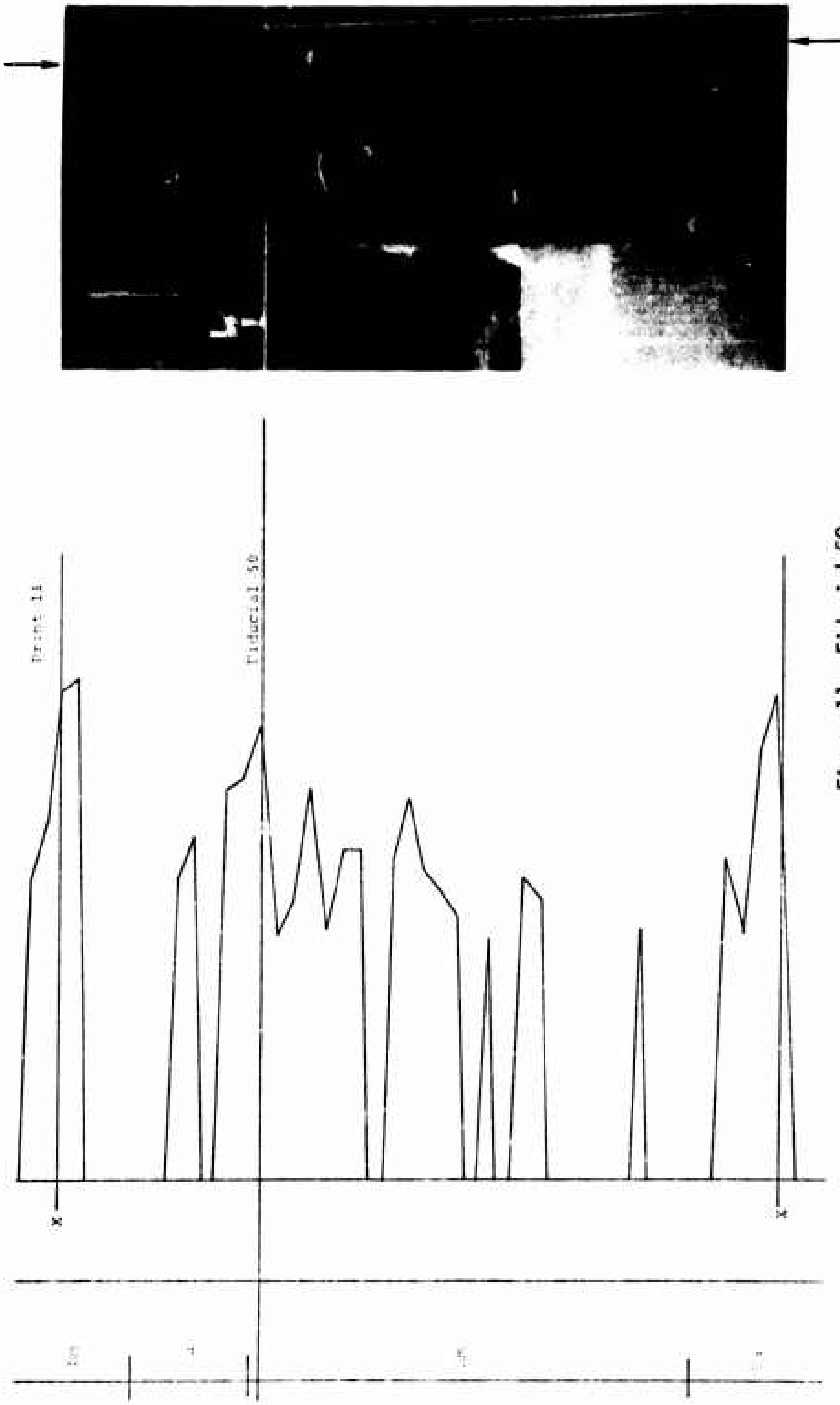

Figure 11. Fiducial 50

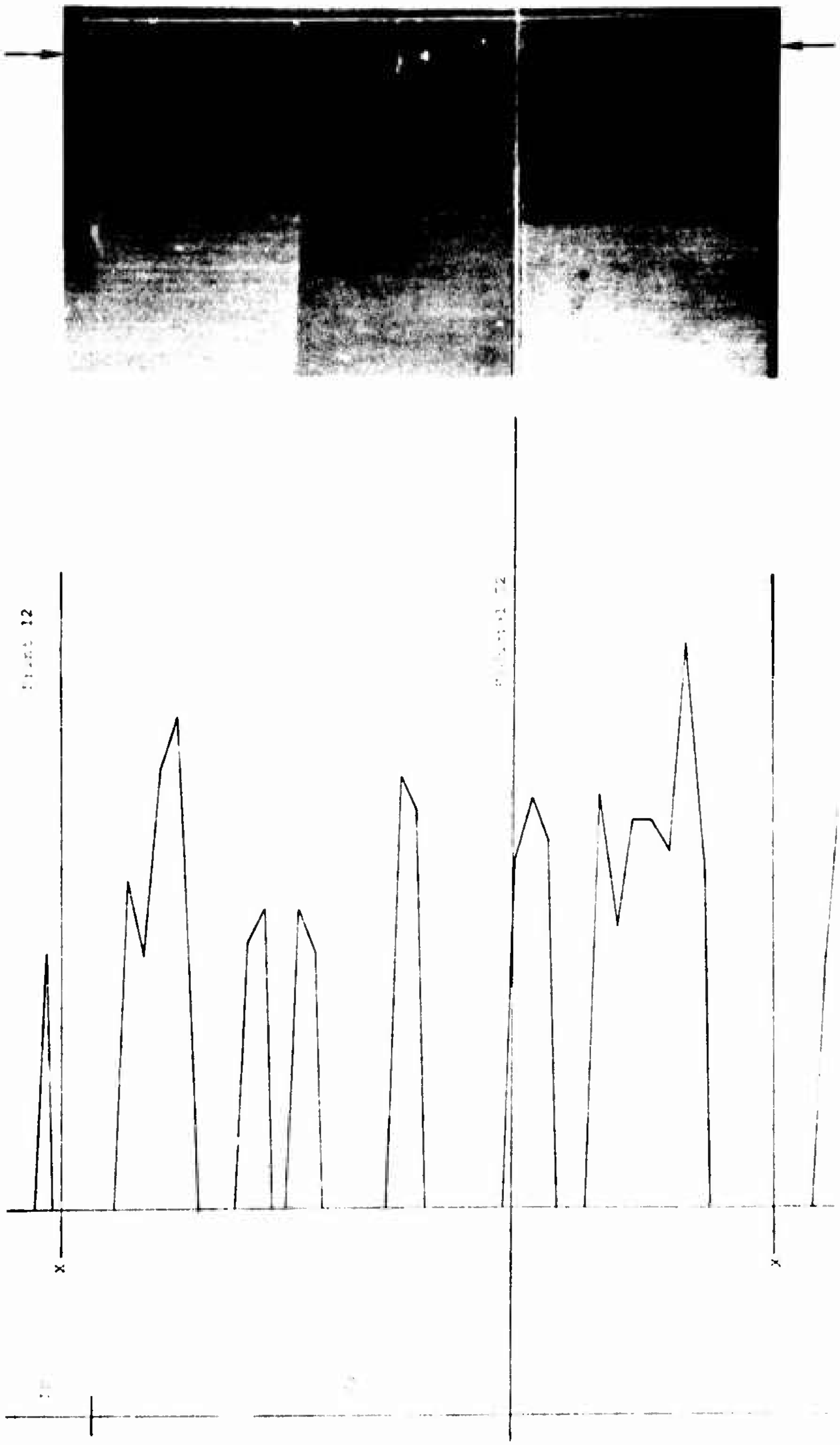

Figure 12. Fiducial 52

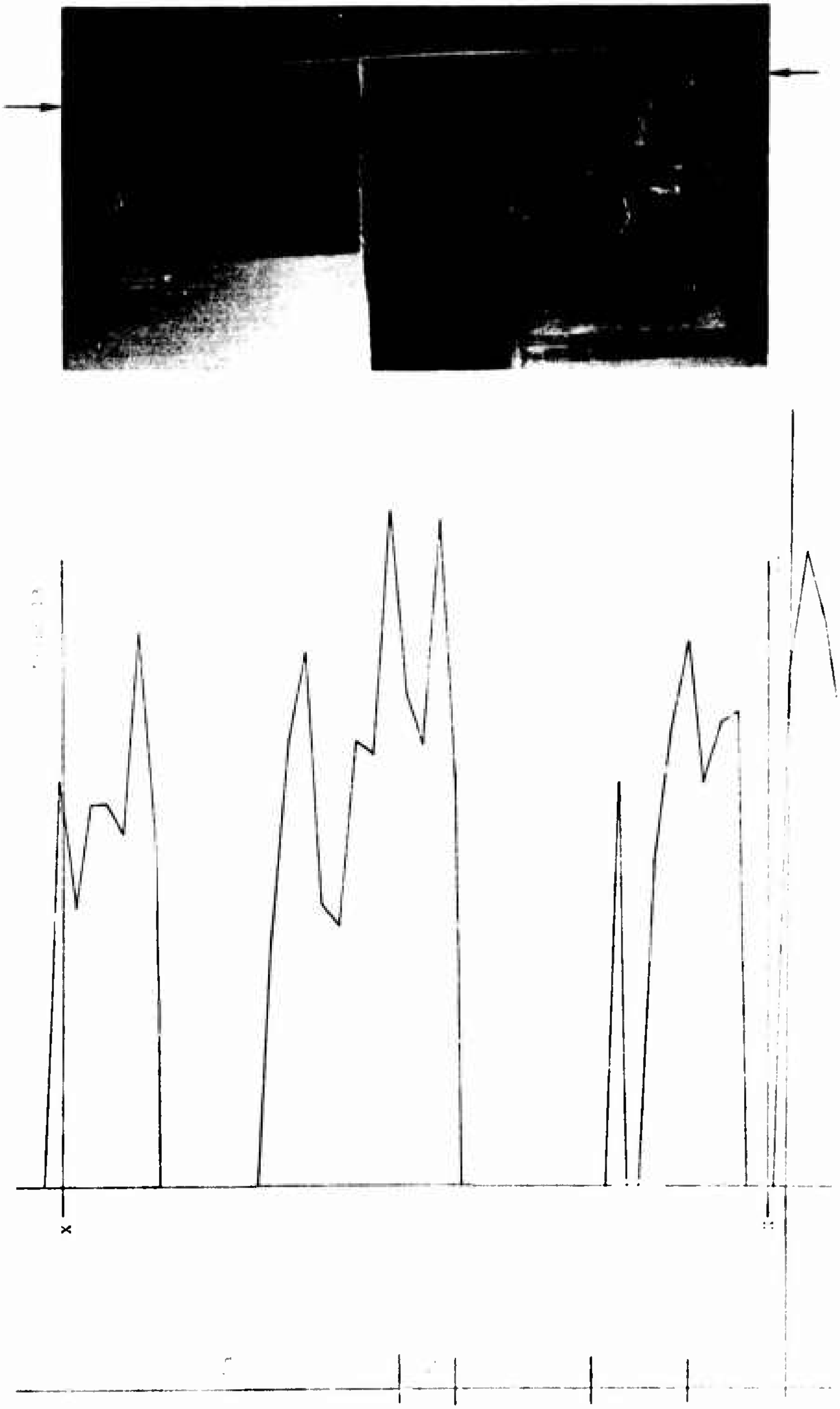

Figure 13. Fiducial 54

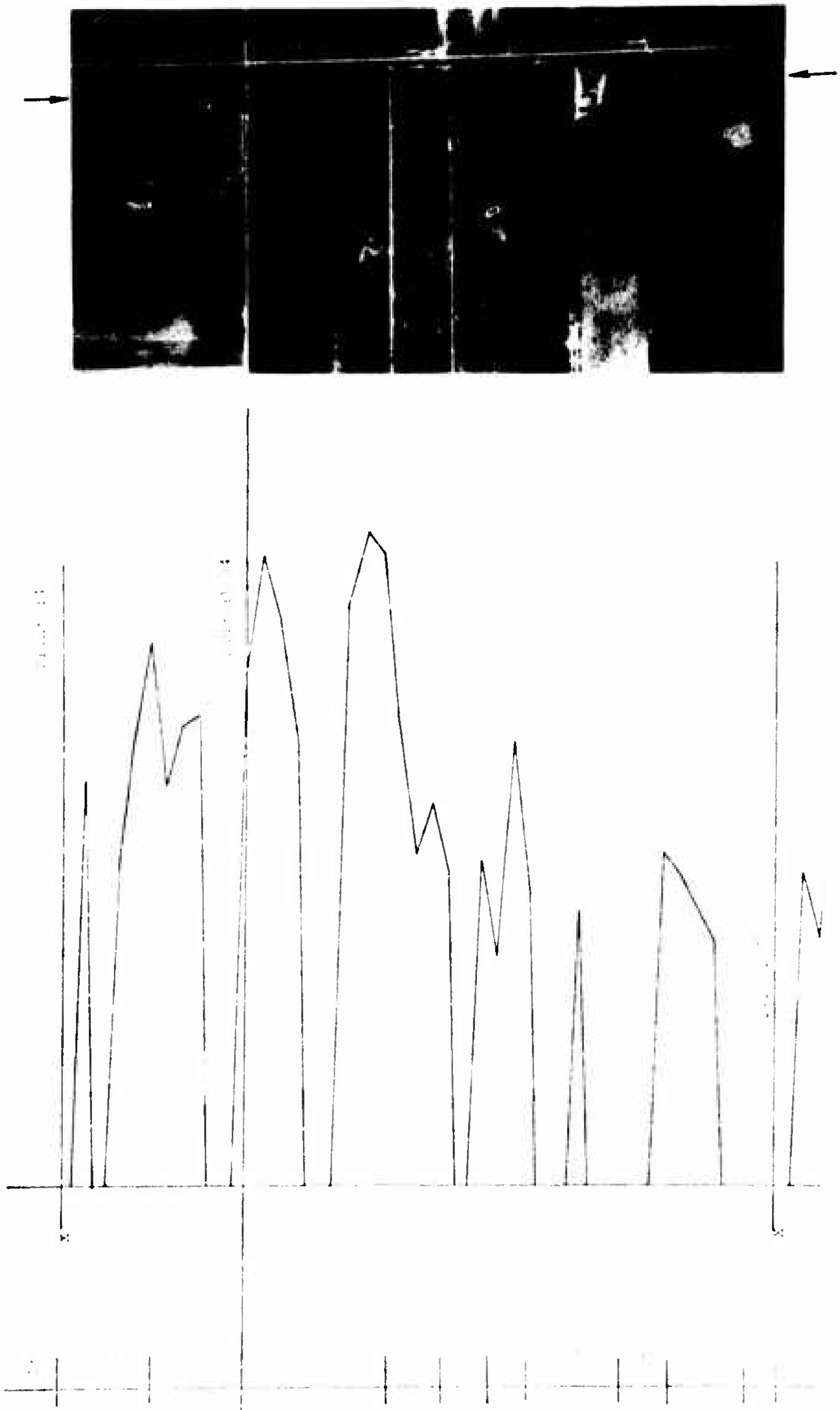

Figure 14. Fiducial 54

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APPENDIX A

DESCRIPTION OF SOIL TYPES

This data taken from

Soil Survey - Finney County, Kansas
Series 1961, No. 30
Issued November, 1965

SOIL LEGEND

SYMBOL	NAME
Ad	Active dunes
An	Alluvial land
Ba	Bayard fine sandy loam
Bp	Bridgeport clay loam
Bx	Broken land
Ch	Church silty clay loam
Cs	Colby loam, saline
Dr	Drummond silt loam
Ha	Harney silt loam, 0 to 1 percent slopes
Hu	Humbarger silt loam
Ka	Keith loam, 0 to 1 percent slopes
La	Las clay loam, moderately deep
Lb	Las clay loam, deep
Lc	Las-Bayard sandy loams
Ld	Las-Las Animas complex
Lk	Las Animas sandy loam
[illegible]	Las Animas-Lincoln loamy sands
Lm	Lincoln soils
Ln	Lismas clay
Lo	Lofton clay loam
Mh	Mansic complex
Mm	Mansker-Potter complex
Mn	Manter fine sandy loam, level
Mr	Manter fine sandy loam, undulating
Mt	Manter-Otero fine sandy loams, undulating
Ot	Otero fine sandy loam, 5 to 15 percent slopes
Ox	Otero gravelly complex
Oy	Otero-Ulysses complex, undulating
Pc	Promise clay, 1 to 3 percent slopes
Ra	Randall clay
Rm	Richfield silt loam, 0 to 1 percent slopes
Rn	Richfield silt loam, 1 to 3 percent slopes
Ro	Richfield silt loam, saline
Rs	Richfield-Spearville complex, 0 to 1 percent slopes
Ru	Richfield and Ulysses complexes, bench leveled
Rw	Rock land
Rx	Roxbury silt loam
Sp	Spearville silty clay loam, 0 to 1 percent slopes
Sr	Spearville complex, 1 to 3 percent slopes, eroded
Sw	Sweetwater clay loam
Tf	Tivoli fine sand
Tv	Tivoli-Vona loamy fine sands
Tx	Tivoli-Dune land complex
Ua	Ulysses silt loam, 0 to 1 percent slopes
Ub	Ulysses silt loam, 1 to 3 percent slopes
Uc	Ulysses silt loam, 3 to 5 percent slopes
Ud	Ulysses loam, undulating
Ue	Ulysses-Colby silt loams, 1 to 3 percent slopes, eroded
Um	Ulysses-Colby silt loams, 3 to 5 percent slopes, eroded
Us	Ulysses silt loam, saline, 0 to 1 percent slopes
Ut	Ulysses silt loam, saline, 1 to 3 percent slopes
Uv	Ulysses and Richfield complexes, saline, bench leveled
Ux	Ulysses and Richfield soils, silted, 0 to 1 percent slopes
Vn	Vona loamy fine sand

WORKS AND

Highways and roads
- Dual
- Good motor
- Poor motor
- Trail

Highway markers
- National Interstate
- U. S.
- State

Railroads
- Single track
- Multiple track
- Abandoned

Bridges and crossings
- Road
- Trail, foot
- Railroad
- Ferries
- Ford
- Grade
- R. R. over
- R. R. under
- Tunnel

Buildings
- School
- Church
- Station

Mines and Quarries

Mine dump

Pits, gravel or other

Power lines

Pipe lines

Cemeteries

Dams

Levees

Tanks

Oil wells

Keith Series

Soils of the Keith series are deep, nearly level, and loamy. They are fertile and well drained, and they have high moisture-holding capacity. These soils are in the uplands. The native vegetation was grass.

In most places the surface layer is dark grayish-brown loam about 9 inches thick. The structure is granular. This layer is easily worked, but it pulverizes if tillage is excessive, and a crust forms after rain. A plowpan is likely to form if tillage is always at the same depth. The transitional layer between the surface layer and the subsoil is about 6 inches thick.

The subsoil is generally grayish-brown, light clay loam, and it has subangular blocky structure. It is easily penetrated by moisture and roots. The subsoil is noncalcareous, but there is a layer of accumulated lime just below the subsoil.

The substratum is light-colored, calcareous, loamy loess. The thickness of the surface layer ranges from 6 to 12 inches, and that of the transitional layer between the surface layer and the subsoil, from 4 to 8 inches. The subsoil ranges from dark grayish brown to brown in color and from 8 to 14 inches in thickness. Depth to calcareous material range from 15 to 30 inches.

The keith soils are less clayey than the Richfield soils. They are darkened by organic matter and are leached of lime to a greater depth than the Ulysses soils. They also have a better defined subsoil.

Keith Loam, 0 to 1 Percent Slopes

This is the only Keith soil mapped inthe county. It is in the uplands in the transitional zone between the sandy soils and the more clayey soils of the High Plains. In some areas the texture of the plow layer is fine sandy loam.

Small areas of Ulysses and Richfield silt loam are mapped with this soil As much as 8 per cent of the acreage is Ulysses silt loam, and about 4 per cent is Richfield silt loam.

This Keith soil is well suited to wheat and grain sorghum. Conserving moisture and controlling wind erosion are the major problems in managing it. Keeping plant

residue on the surface provides protection from erosion and helps to conserve moisture. Contour farming, stripcropping, and terracing are also desirable practices. (Capability unit IIc-1, dryland; capability unit I-1, irrigated; Loamy Upland range site; Silty Upland windbreak suitability group).

Mansic Series

The soils of the Mansic series are moderately steep. They are calcareous and are loamy. These soils are on the uplands. They are well drained and have high moisture-holding capacity. The native vegetation was grass.

In most places the surface layer is dark grayish-brown clay loam that is about 8 inches thick and has granular structure. This layer is friable and takes water readily, but it erodes easily. The soil material in the surface layer grades to that in the subsoil.

The subsoil is generally clay loam, and it has granular structure. It is brown in the upper part, but the color grades to very pale brown in the lower part. The subsoil is calcareous and contains numerous lime concretions. It is permeable to moisture and plant roots. Below the subsoil is loamy Plains outwash.

The texture of the surface layer ranges from heavy loam to clay loam. The reaction of the surface layer ranges from calcareous. The texture of the subsoil ranges from medium to heavy clay loam.

The Mansic soils are more clayey and less silty than the Ulysses soils. Their subsoil lacks the strong accumulation of lime that is typical in the subsoil of the Mansker soils.

Mansic Complex: (0 to 15 per cent slopes)

This is a complex of Mansic clay loams, on the sides of narrow valleys, and of grayish-brown, loamy soils formed in alluvium on the floors of valleys. The Mansic soils occupy both sides of the valley walls. They make up about 57 per cent of the acreage of the complex. The soils formed in alluvium are on valley floors that are less than 150 feet wide. They occupy about 20 per cent of the acreage in the complex.

This complex occurs with Lismas clay, the soils of the Mansker-Potter complex, and Rock land, and areas of these associated soils were included in mapping. Inclusions of Lismas, Mansker, and Potter soils make up about 8 per cent of the acreage in the complex, inclusions of Ulysses soils make up about 10 per cent, and inclusions of Colby soils make up about 5 per cent.

The soils of this complex are not suitable for cultivation, because the areas that are moderately steep are highly susceptible to erosion. They are productive if kept in grass. Grazing must be managed, however, so that growth of the best native forage plants will be encouraged. This can be done by using a proper stocking rate and practicing deferred grazing or rotation deferred grazing. Locating fences, salt, and water properly will help distribure livestock over the range. (Capability unit VIe-1, dryland; not placed in an irrigated capability unit; Loamy Upland range site; Silty Upland windbreak suitability group).

Manter Series

Deep, noncalcareous, sandy soils that are nearly level and gently sloping are in the Manter series. These soils are fertile. They are well drained and have moderate moisture-holding capacity. The native vegetation was grass.

In most places the surface layer is dark grayish-brown fine sandy loam about 8 inches thick. It has granular structure and is porous. The surface layer takes water readily, but is susceptible to wind erosion when it is dry and unprotected.

The subsoil has granular structure and is generally brown fine sandy loam about 18 inches thick. It is noncalcareous and is readily penetrated by moisture and roots. Just below the subsoil is calcareous, sandy, wind-deposited material that contains concretions and threads of lime. This sandy material is underlain, at variable depths, by calcareous silt loam or loam, which is generally within 5 feet of the surface.

In areas that have been cultivated, the surface layer consists of a thin, winnowed layer of loamy fine sand. The thickness of the surface layer and the depth to calcareous material vary according to the shape and degree of the slope. Depth to calcareous material ranges from 12 inches, on convex ridgetops, to 48 inches, on the concave slopes between the ridges. The texture of the subsoil ranges from fine sandy loam to light loam.

The Manter soils are darker and less calcareous than the Otero soils. They have a darker, less sandy surface layer than the Vona soils.

Manter Fine Sandy Loam Undulating:(0 to 3 per cent slopes)

This soil is in areas of convex slopes separated by small, nearly level areas. The landscape where it occurs is dotted by small depressions where water is ponded briefly after rains.

Areas of Ulysses, Keith, Otero, and Vona soils were included with this soil in mapping. Ulysses soils occupy about 10 per cent of the acreage; Keith soils, about 6 per cent; and Otero soils, about 4 per cent. Vona soils occupy only a small acreage.

This Manter soil is suited to wheat and grain sorghum, but conserving moisture and controlling wind erosion are problems. Stubble mulching helps to protect this soil from erosion, and stripcropping is another desirable practice. Contour farming and terracing may be beneficial in some places, but they are generally impractical, because of the complex slopes. (Capability unit IIIe-6, dryland; capability unit IIe-2, irrigated; Sandy range site; Sandy Upland windbreak suitability group).

Randall Series

The Randall series consists of compact silty clays in undrained depressions that receive runoff from surrounding areas. These soils have very slow permeability. The native vegetation was grass.

The surface layer is gray clay or silty clay, and the subsoil is clayey and has blocky structure. These soils are very hard when dry and very firm when moist. Reaction ranges from calcareous at the surface to noncalcareous at a depth of 48 inches. The silty clay is 24 to 48 inches thick over the substratum of more permeable, loamy material. These soils formed in areas that receive an excessive amount of moisture.

The Randall soils are more clayey, more compact, and less well drained than the Lofton soils. Also they lack the strongly defined subsoil that is characteristic of the Loston soils.

Randall Clay: (0 to 1 per cent slopes)

This is the only Randall soil mapped in this county. It is in depressions that range from a few inches to almost 10 feet in depth. The depressions occur throughout the plains area. They range from less than 10 acres to more than 80 acres in size.

This soil is generally farmed along with the adjoining soils. The crops are frequently drowned out, however, of the areas are too wet for a crop to be planted. The frequency and amount of ponding are variable in the different depressions, depending on the extent of the drainage area. Wind erosion is a hazard when the areas are bare and dry.

Ponding is a hazard to the native grasses. Most areas of this soil that are not cultivated are either bare or have a sparse stand of western wheatgrass. In many places burragweed and smartweek grow in the depressions. (Capability unit VIw-2, dryland: not placed in an irrigated capability unit, range site, or windbreak suitability group).

Rm

Richfield Series

In the Richfield series are deepk nearly level and gently sloping, loamy soils of the upland. These soils are fertile. They are well drained and have high moisture-holding capacity. The native vegetation was grass.

In most places the surface layer is dark grayish-grown silt loam about 6 inches thick. Its structure is granular. This layer is easily worked, but it pulverizes if tillage is excessive, and a crust forms after rains. A plowpan is likely to form if tillage is always at the same depth. The transitional layer between the surface layer and the subsoil is about 4 inches thick.

The subsoil has subangular blocky structure and is generally dark grayish-brown silty clay loam about 12 inches thick. It is hard when dry and firm when moist, but it is permeable to moisture and roots. It is noncalcareous, but there is a layer of accumulated lime just below the subsoil.

The substratum is light-colored, calcareous, silty loess. The thickness of the surface layer ranges from 5 to 10 inches, that of the transitional layer between the surface layer and the subsoil ranges from 2 to 6 inches, and that of the subsoil ranges from 8 to 14 inches. Depth to calcareous material ranges from 12 to 20 inches.

The Richfield soils have a less clayey, less compact subsoil than the Spearville soils, and they are more clayey and have a more strongly defined subsoil horizon than the Ulysses soils. The Richfield soils have a more clayey subsoil than the Keith soils. The lower part of their subsoil is less clayey than that of the Harney soils.

Richfield Silt Loam, 0 to 1 Per cent Slopes

This nearly level soil is in the uplands. It has a thicker profile than the more sloping Richfield soils. Depth to calcareous material ranges from 15 to 20 inches.

In the northwestern part of the county, areas of Ulysses silt loam and Keith loam are mapped with this soil. In the central and eastern parts, small areas of Harney silt loam and of Spearville silty clay loam are mapped with it. The Ulysses soil makes up about 10 per cent of the acreage, and the Keith soil, about 5 per cent.

This Richfield soil is well suited to wheat and grain sorghum. Conserving moisture and controlling wind erosion are the major problems in managing it. Keeping plant residue on the surface will conserve moisture and provide protection from erosion. Contour farming, stripcropping, and terracing are other good practices. (Capability unit IIc-1, dryland; capacility unit I-1, irrigated: Loamy Upland range site; Silty Upland windbreak suitability group).

Ulysses Series

The Ulysses series consists of deep, loamy, well-drained, nearly level to sloping soils of the upland. These soils are fertile, and they have high moisture-holding capacity. The native vegetation was grass.

In most places the surface layer is dark grayish-brown silt loam about 6 inches thick. It has granular structure. It is easily worked, but if tillage is excessive, the soil material pulverizes and a crust forms after rains. When dry, the soil material blows easily.

The subsoil is generally dark gravish-brown, friable silt loam or light silty clay loam. It is easily penetrated by moisture and roots. Below the subsoil is light-colored, calcareous, silty loess.

The thickness of the surface layer ranges from 4 to 8 inches. Where the Ulysses soils occur with more sandy soils, the texture of the surface layer is loam and the texture of the subsoil is loam or light clay loam. The subsoil of the Ulysses soils is poorly defined, and its structure ranges from granular to subangular blocky. Its reaction ranges from calcareous at the surface to noncalcareous to a depth of 15 inches.

The Ulysses soils are less clayey than the Richfield soils, and they have a more poorly defined subsoil than the Richfield and Keith soils. They are not dark colored to so great a depth as are the Keith soils. The Ulysses soils are darker colored and less calcareous than the Colby soils, and their subsoil is more strongly defined.

Ub

Ulysses Silt Loam, 1 to 3 Per cent Slopes

This soil is on weakly convex slopes. In much of the acreage, it is calcareous to the surface.

Where this soil occurs with more sandy soils, areas of Manter fine sandy loam make up as much as 5 per cent of the acreage. Small areas of Richfield silt loam and a small acreage of Keith loam were also included in mapping. The Richfield soil makes up about 12 per cent of the acreage.

This Ulysses soil is well suited to wheat and grain sorghum, but conserving moisture and controlling erosion by wind and water are problems. Terraces, contour farming, and good management of plant residue are essential. Stripcropping is also a good practice. (Capability unit IIIe-1, dryland; sapacility unit IIe-4, irrigated; Loamy Upland range site; Silty Upland windbreak suitability group).

Ulysses Silt Loam, 3 to 5 Per cent Slope

This soil is on weakly convex slopes, mainly within the drainage area of the Pawnee River. Much of it is calcareous to the surface. Mapped with it are small areas of Richfield and Mansic soils and a small acreage of Mansker soils. About 7 per cent of the acreage is Richfield silt loam, and about 5 per cent is Mansic clay loam.

Wheat and grain sorghum are the main crops grown on this Ulysses soil. Conserving moisture and controlling erosion by wind and water are the principal management problems. Terraces, contour farming, and good management of plant residue are essential, and stripcropping is a good practice. (Capability unit IVe-2, dryland; not placed in an irrigated capability unit; Loamy Upland range site; Silty Upland windbreak suitability group).

Ulysses-Colby Silt Loams, 1 to 3 Per cent Slopes, Eroded

This complex of Ulysses and Colby soils is on weakly convex slopes. Ulysses silt loam makes up 50 to 65 per cent of the acreage, and Colby silt loam makes up 25 to 40 per cent. About 10 per cent of the acreage is Richfield silt loam.

The areas of Colby silt loam were formerly Ulysses silt loam, but erosion stripped away the dark-colored, original surface layer and exposed the lighter colored, more calcareous subsoil. The Colby soil of this complex is generally on the tops or crests of slopes, where the effects of erosion have been more pronounced than on the lower parts of the slopes.

The soils of this complex are well suited to wheat and grain sorghum. Careful management will conserve moisture and control erosion by wind and water. Terracing, contour farming, and good management of crop residue are essential, and stripcropping is a desirable practice. (Capability unit IIIe-1, dryland; capacility unit IIe-4, irrigated; Limy Upland range site; Silty Upland windbreak suitability group).

CRINC LABORATORIES

Chemical Engineering Low Temperature Laboratory

Remote Sensing Laboratory

Flight Research Laboratory

Chemical Engineering Heat Transfer Laboratory

Nuclear Engineering Laboratory

Environmental Health Engineering Laboratory

Information Processing Laboratory

Water Resources Institute

Technical Transfer Laboratory

Air Pollution Laboratory

Satellite Applications Laboratory